ECONOMIC COMPARISON OF COAL FEEDING SYSTEMS IN COAL GASIFICATION--LOCK HOPPER VS SLURRY

William C. Morel

U.S. Department of the Interior, Bureau of Mines
Process Evaluation Office--MMRD
P.O. Box 880
Morgantown, West Virginia 26505

INTRODUCTION

Coal feeding to the various pressurized coal gasification processes presents certain technical problems that will have to be solved. Two feeding systems being considered are the lock hopper and coal slurry. The coal slurry system has the advantage of being simple to operate with a good reliability, but erosion problems in the circulating pumps and injection valves will have to be solved. The lock hopper system has the advantage of feeding a dry coal without solvent dilution, but will also have erosion problems in the valves and will require a complex cycle control system.

An economic comparison was made of the two feeding systems based on the Bituminous Coal Research's Bi-Gas process using a Western Kentucky No. 11 coal, assuming the two systems are technically feasible. The estimates are based on January 1976 cost indexes. Average selling prices of the gas were determined by using discounted cash flow rates of 12, 15, and 20 percent at various coal costs. No inflation factors are considered for the life of the plant. Pollution abatement considerations have been incorporated. Some of the economic and technical details of the Bi-Gas process are included.

Lock Hopper System

The Bi-Gas process is a two-stage coal gasification system to convert bituminous and subbituminous coal to a high-Btu pipeline gas. Figure 1 is a flowsheet of the process (1) and includes the following steps:

1. Coal preparation, which includes crushing, screening, sizing of the run-of-mine coal, and conveying the sized coal to the lock hopper feeding system (2) (not shown in figure 1).
2. In the upper section of the gasifier, coal contacts the hot synthesis gas produced in the lower section and is partially converted to methane and more synthesis gas. The entrained char in the raw product gas is separated and recycled to the lower section, where it is gasified to produce synthesis gas and heat required in the upper section.
3. Shift conversion of the synthesis gas to H_2:CO ratio of 3.1:1.
4. The hot-carbonate purification system reduces the CO_2 content of the shifted gas to 0.5 percent and removes essentially all the H_2S and COS. Zinc oxide towers are provided for residual sulfur cleanup.
5. The heating value of the clean gas is increased to 946 Btu by reacting hydrogen with 99.8 percent of the CO in the presence of a nickel catalyst to form methane and water.
6. After gas cooling, the moisture content of the product is reduced to 7 pounds per million standard cubic feet.

The gasifiers are designed to operate at an outlet pressure of 1,160 psig and at maximum temperatures of 1,700° F and 2,700° F for the upper and lower sections, respectively. The thermal efficiency of the plant, using a Western Kentucky No. 11 coal, is 65.3 percent, based on a coal heating value of 13,070 Btu per pound.

Slurry Feeding System

The pulverized coal is mixed with hot condensate to produce a 50-50 weight-percent coal-water slurry and then raised to the system pressure of approximately 1,200 psig with triplex reciprocating pumps. After being preheated to 430° F, the coal slurry is dried in a spray dryer with gasifier product gas that vaporizes the water. The coal and humidified gas at 660° F flow to a cycle separator where the coal drops into a coal hopper and is pneumatically fed to the upper section of the gasifier. This feeding system (3) is illustrated in figure 2. The rest of the integrated plant, (4) shown in figure 3, is the same as described in the lock hopper system except for some changes in the shift conversion, gasification, and heat recovery units owing to shifting of heat loads. The thermal efficiency of the plant is the same as that of the lock hopper system--65.3 percent.

Capital Investment

An economic evaluation was made of an integrated plant sized and designed to produce 250 million scf of high-Btu gas (946 Btu/scf) by two-stage gasification of Western Kentucky No. 11 coal followed by shift conversion, purification, methanation, and pollution control. The total investment is estimated to be $533.3 million for the lock hopper system, or $92.4 million higher than for the coal slurry system.

Table 1 is a capital requirement comparison of the two feeding systems. Detailed cost summaries of the major processing units are not included, but the costs of the individual units are listed. General facilities include administrative buildings, shops, warehouses, railroad spurs, rolling stock, roads, waste water treatment, and fences. The costs of steam and power distribution, cooling water towers, plant and instrument air, fire protection, and sanitary water are included in plant utilities.

Operating Cost

Table 2 presents the estimated operating cost comparison for the lock hopper and coal slurry feeding systems. An assumed 90-percent operating factor allows 35 days for downtime, two 10-day shutdowns for equipment inspection and maintenance, and 15 days for unscheduled operational interruptions. With labor at $6 per hour, payroll overhead at 30 percent of payroll, and depreciation at 5 percent of the subtotal for depreciation, allowing credit for sulfur recovered at $25 per ton, and with the cost of coal as a variable, the following operating costs are derived:

Cost of coal per ton	Per year, MM		Per MMBtu	
	Lock hopper system	Slurry feeding	Lock hopper system	Slurry feeding
$11	$128.0	$115.8	$1.64	$1.48
13	137.1	125.0	1.75	1.60
15	146.3	134.1	1.87	1.72

Based on a 330-day operating year for the plant and allowing credit for sulfur produced, with coal costs and discounted cash flow (DCF) rates as parameters, the average selling prices of the gas per Mscf and per MMBtu for the two systems are shown in the following table:

Coal cost, dollars per ton	Gas selling price											
	Dollars per Mscf						Dollars per MMBtu					
	12-pct DCF		15-pct DCF		20-pct DCF		12-pct DCF		15-pct DCF		20-pct DCF	
	Lock hopper	Coal slurry	Lock hopper	Coal slurry	Lock hopper	Coal slurry	Lock hopper	Coal slurry	Lock hopper	Coal slurry	Lock hopper	Coal slurry
11	2.61	2.28	2.97	2.58	3.64	3.13	2.76	2.41	3.14	2.73	3.85	3.31
13	2.72	2.39	3.08	2.69	3.75	3.24	2.88	2.53	3.26	2.84	3.96	3.42
15	2.83	2.50	3.19	2.80	3.86	3.35	2.99	2.64	3.37	2.96	4.08	3.54

The DCF computer program takes into account the capital expenditure, based on 100-percent equity, prior to startup so that the interest during construction is deleted from the capital requirement. Provisions are made for recovery of the working capital in the 20th year.

Unit Cost Summary

The selling price used to determine the high-cost elements in the process was based on a 15-percent DCF for a 20-year project life, with coal at $13 per ton. A breakdown of the cost elements for the two systems is shown in table 3.

SUMMARY

As noted in table 1, the lock hopper feeding total investment is $92.4 million, or 21 percent higher than the slurry feeding system investment. Approximately $69 million is attributed to difference in feeding systems.

The operating cost of the lock hopper system is about 10 percent higher than that of the slurry feeding system. Increases in maintenance, overhead, and indirect and fixed costs, which are directly related to the capital investment, represent the main difference.

The average selling price was based on three coal costs ($11, $13, and $15 per ton) and three DCF rates of return (12, 15, and 20 percent). Over this range the selling price for the lock hopper system increases from $0.33 to $0.51 per Mscf of product, or $0.35 to $0.54 per MMBtu. This increase is approximately 15 percent.

CONCLUSION

Results of this study indicate the slurry feeding system is more economical than the lock hopper system, when used to feed a high-pressure (1,200 psig) two-stage gasifier in the Bi-Gas process. It must be kept in mind, however, that this study was conducted under the assumption that the technical problems for both the coal slurry and lock hopper systems have been solved.

REFERENCE

(1) Intrabureau Report No. 76-34, "An Economic Comparison of Coal Feeding Systems - Lock Hopper Versus Slurry Feeding. 250-Million-Scfd High-Btu Gas Plant, Bituminous Coal Research Process, Western Kentucky No. 11 Coal." Process Evaluation Group, Bureau of Mines, Morgantown, W. Va., June 1976.

(2) Based on lock hopper design data of the Synthane 72-tpd pilot plant in Bruceton, Pa.

(3) "Feasibility Study of a Coal Slurry Feeding System for High Pressure Gasifiers." Prepared by Air Products and Chemicals, Inc., Allentown, Pa., for Office of Coal Research, U.S. Department of the Interior, Washington, D.C., R & D Report No. 68, Final Report, June 1971.

(4) Intrabureau Report No. 76-35, "250-Million-Scfd High-Btu Gas Plant. Bituminous Coal Research Process - Western Kentucky No. 11 Coal, An Economic Analysis." Process Evaluation Group, Bureau of Mines, Morgantown, W. Va., June 1976.

TABLE 1. - Capital requirements, comparison of lock hopper system with slurry feeding system

Unit	Lock hopper system	Slurry feeding system	Difference
Coal preparation.....	$14,295,400	$14,295,400	0
Slurry preparation.....	-	16,435,000	$+68,743,000
Lock hopper system.....	85,178,000	-	
Gasification.....	20,698,500	20,698,500	0
Heat recovery No. 1.....	3,402,400	-	+3,402,400
Dust removal.....	2,341,100	2,341,100	0
Shift conversion.....	10,033,200	7,700,000	+2,333,200
Heat recovery No. 2 or 1	8,143,900	23,392,600	-15,248,700
Purification.....	75,713,300	75,281,100	+432,200
Methanation.....	18,782,900	18,782,900	0
Heat recovery No. 3 or 2	21,718,000	21,718,000	0
Drying.....	873,500	873,500	0
Oxygen plant.....	51,975,000	51,975,000	0
Sulfur recovery.....	2,312,500	2,312,500	0
Flue gas processing.....	16,033,300	16,033,300	0
Steam plant.....	22,822,500	20,910,000	+1,912,500
Plant facilities.....	26,574,200	21,956,200	+4,618,000
Plant utilities.....	38,089,700	31,470,500	+6,619,200
Total construction.....	418,987,400	346,175,600	+72,811,800
Initial catalyst requirements.....	2,559,800	2,348,100	+211,700
Total plant cost.....	421,547,200	348,523,700	+73,023,500
Interest during construction.....	63,232,000	52,278,600	+10,953,400
Subtotal for depreciation.....	484,779,200	400,802,300	+83,976,900
Working capital.....	48,477,900	40,080,200	+8,397,700
Total investment...	533,257,100	440,882,500	+92,374,600

TABLE 2. - Annual operating cost, comparison of lock hopper system with slurry feeding system

Cost item	Lock hopper system	Slurry feeding system	Difference
Direct cost:			
Raw materials:			
Coal at $11/ton	$50,294,400	$50,294,400	0
Raw water	1,176,100	1,211,800	$-35,700
Catalyst and chemicals	2,517,300	2,504,200	+13,100
Methane	455,600	455,600	0
Subtotal	54,443,400	54,466,000	-22,600
Direct labor	2,470,300	2,522,900	-52,600
Direct labor supervision	370,500	378,400	-7,900
Subtotal	2,840,800	2,901,300	-60,500
Maintenance labor	7,815,000	6,465,000	+1,350,000
Maintenance supervision	1,563,000	1,293,000	+270,000
Maintenance material and contracts	11,722,500	9,697,500	+2,025,000
Subtotal	21,100,500	17,455,500	+3,645,000
Payroll overhead	3,665,600	3,197,800	+467,800
Operating supplies	4,220,100	3,491,100	+729,000
Total direct cost	86,270,400	81,511,700	+4,758,700
Indirect cost	11,264,600	9,539,200	+1,725,400
Fixed cost:			
Taxes and insurance	8,430,900	6,970,500	+1,460,400
Depreciation	24,238,900	20,040,100	+4,198,800
Total, before credit	130,204,800	118,061,500	+12,143,300
Sulfur credit	2,226,700	2,226,700	0
Operating cost, after credit	127,978,100	115,834,800	+12,143,300

TABLE 3. - Unit cost comparison

Process unit	Cost per Mscf of product	
	Lock hopper system	Slurry feeding system
Coal preparation	$0.13	$0.13
Gasification	1.32	1.41
Lock hopper system	.50	-
Slurry preparation.....	-	.16
Dust removal	.02	.02
Shift conversion	.18	.05
Purification	.64	.63
Methanation	.17	.17
Drying	.01	.01
Sulfur recovery	-	-
Flue gas processing	.11	.11
Total	3.08	2.69

Basis: Coal at $13/ton - 15% DCF.

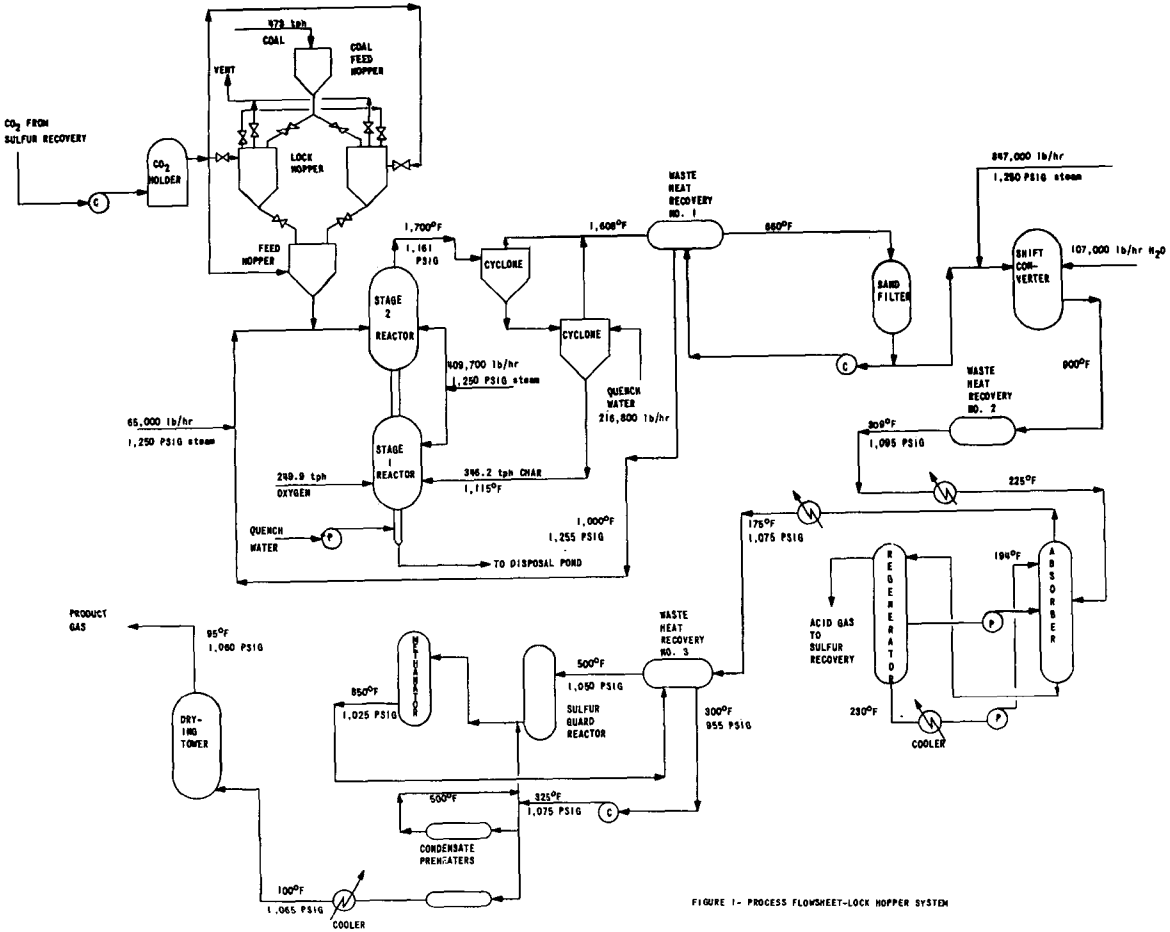

FIGURE 1- PROCESS FLOWSHEET-LOCK HOPPER SYSTEM

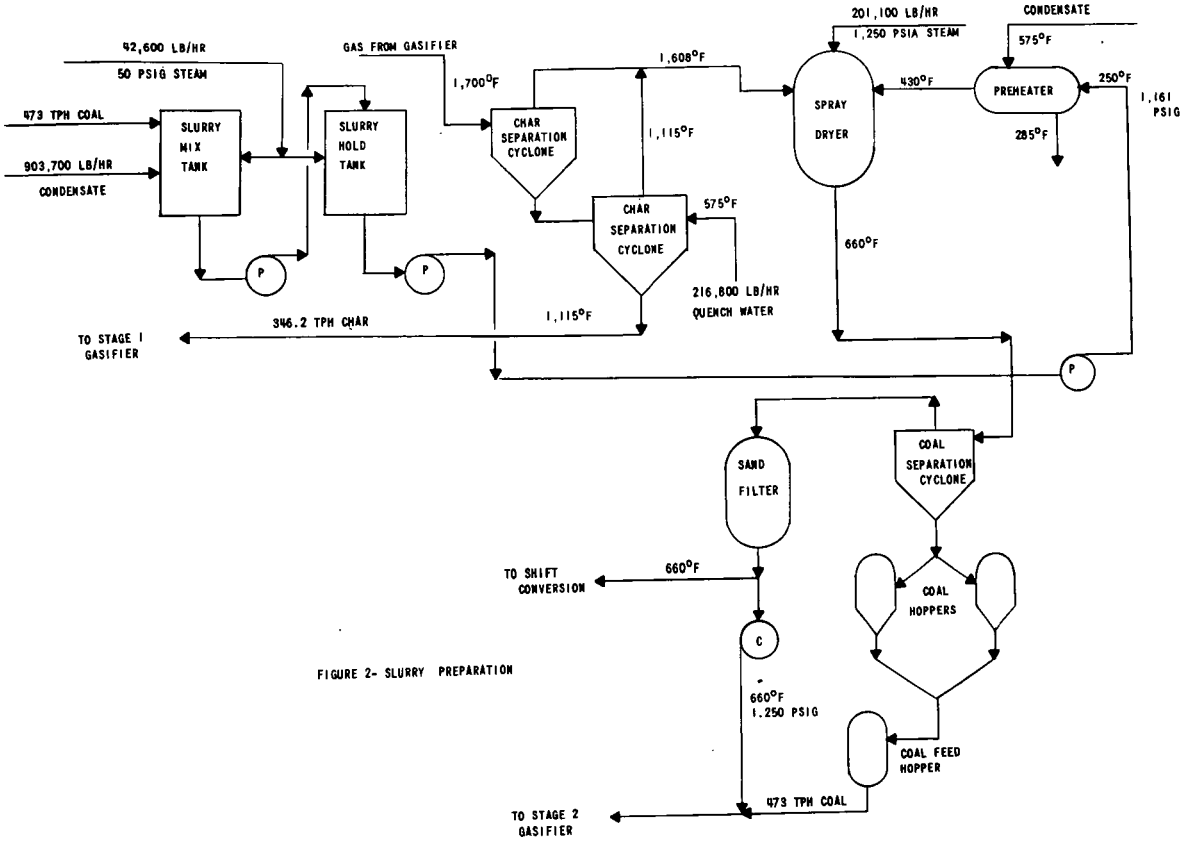

FIGURE 2- SLURRY PREPARATION

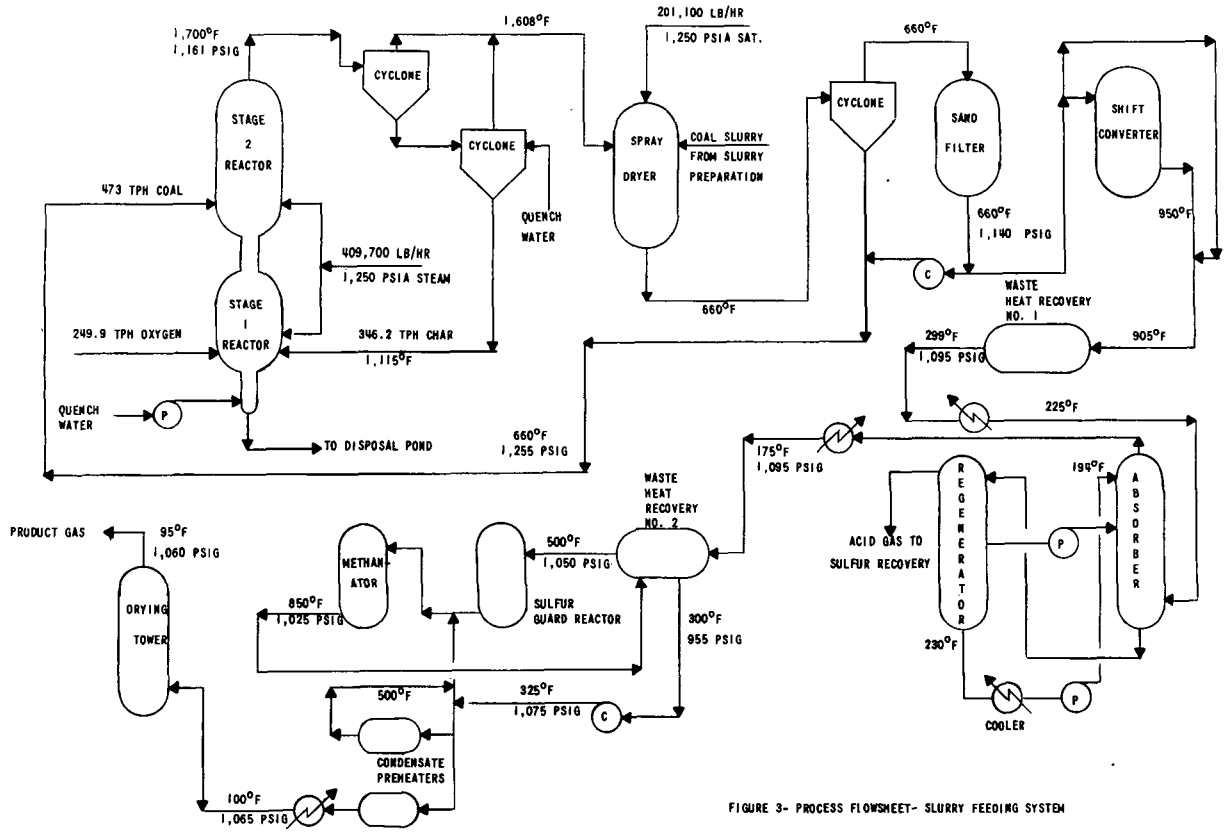

FIGURE 3- PROCESS FLOWSHEET- SLURRY FEEDING SYSTEM